Laboratory Test	Linx	LGE	Units
White Noise Threshold (TOV @ -53 dBm moderate level)	15.1	15.5	dB

Table 10 White noise performance

109. **Table 11** contains the multipath delay range test results for both prototype units. A significant increase in pre-echo range can be observed and compared to that offered in past VSB decoder generations, which is advantageous in hilly outdoor reception situations near the fringe of the coverage area as well as in near urban areas with no direct line-of-sight to the transmitter (e.g., "concrete canyons" of major downtown areas).

Laboratory Test	Linx		LGE		Units
-10 dB echo	-30	+39	-49	+49	usec

Table 11 Multipath delay range.

110. From **Table 12**, it can be observed that severe static multipath was handled by both prototypes, with minimal noise enhancement. Brazil E is a pathological case with three 100% ghosts, each 1 usec longer than the next, and exactly phased the same. It is supposed to represent the worst-case condition for a single-frequency network (SFN) at one particular location where three signals are exactly equal in strength. Excluding this special, unique case, only 3 or 4 dB extra signal strength is needed in the main DTV signal to overcome the noise enhancement in the equalizer due to these severe multipath conditions. Note that some of the C/N values are less than the white Gaussian noise threshold value. This is due to the definition used at CRC for describing the multipath. All carrier signal levels (signal plus pilot) are referenced to the *non*-ghosted signal, so when some of the multipath ensembles are created with very short ghosts, these short ghosts added in phase with the original signal to provide a greater signal level than without the ghost.

Laboratory Test	Linx	LGE	Units
Brazil A *Static* Ensemble plus white noise	15.3	15.6	C/N (dB)
Brazil B *Static* Ensemble plus white noise	19.4	18.6	C/N (dB)
Brazil C *Static* Ensemble plus white noise	12.5	14.4	C/N (dB)
Brazil D *Static* Ensemble plus white noise	13.0	14.5	C/N (dB)
Brazil E *Static* Ensemble plus white noise	22.8	23.8	C/N (dB)
Special Brazil C *Static* Ensemble plus white noise	12.6	16.5	C/N (dB)

Table 12 *Static* ensemble multipath plus noise performance.

111. Even when looking at *static* ensembles in **Table 13** where one of the paths is increased until TOV is reached, 0 dB (100%) ghosts are canceled in addition to the other "lower-level" ghosts. While the 4th generation VSB decoder chips performed significantly better than earlier receivers and work well in both outdoor and indoor reception venues with directional antennas, this level of 5th generation multipath performance has not been achieved in any of the previous generations of VSB chips.

Laboratory Test	Linx	LGE	Units
ACATS #286 Static Ensemble, strongest ghost level	0	0	dB
Modified Brazil C Static Ensemble, strongest ghost level	0	1.3	dB
Modified Brazil D Static Ensemble, strongest ghost level	0	0	dB

Table 13 Static ensemble multipath with one strong component performance.

112. Finally, NTSC-into-DTV interference testing was performed, as shown in **Table 14.** The co-channel interference results indicate an ability to reject the strong NTSC co-channel to about 3-4 dB, D/U (i.e., average DTV signal power to peak envelope sync NTSC power). The adjacent channel NTSC interference is rejected to values beyond the –40 dB, D/U value.

Laboratory Test	Linx	LGE	Units
Co-channel	3.9	3.1	dB, D/U
Lower Adjacent Channel	-43.7	-42.0	dB, D/U
Upper Adjacent Channel	-39.9	-41.8	dB, D/U

Table 14 NTSC interference rejection.

113. Note that the above tests at the CRC labs are 2-3 years old and made on *early* prototype receivers (designed with FPGA chips). Both chip manufacturers have since received their initial integrated chips and have stated that improvements over the prototype hardware have been achieved. Both companies also state that fifth generation VSB consumer products will be available on the market this year (2005), well before the April 2006 date on which the first testing of digital signals of a limited number of stations can begin under SHVERA.

114. Even critics of the 8-VSB system have been impressed with the 5G-receiver performance in severe multipath sites. After testing the 5G prototype in Baltimore at the same sites at which previous VSB decoders failed, Sinclair Broadcasting put out a press release on June 8, 2004 **(Ref 19)**. "We are pleased to see the progress made by Zenith that will allow consumers to easily receive free digital television broadcasts in their homes. Broadcasters and consumers can now look forward to robust DTV service delivered over-the-air without having to subscribe to cable or satellite," said Nat Ostroff, Vice President, New Technology, Sinclair Broadcast Group. He went on to say: "[T]he innovations in the fifth-generation integrated circuit allow it to lock onto signals in severe multipath environments even when the ghosts have long delays or are larger than the main signal."

115. In a similar report, engineer, consultant, and author Mark Schubin in his "Monday Memo" on Thursday July 22, 2004 **(Ref 20)**, was apparently not able to wait until the following Monday to publish what he had learned. He stated: "Count me among the believers in the fifth-generation LG/Zenith ATSC receiver! We just did a test this morning in my apartment, and I thought the news was too important not to release immediately. With a simple loop antenna, with no care in the positioning, we were able to pull in seven DTT stations reliably. When I say 'reliably', I mean not only that the pictures and sound were okay but that people could move

around the room and I could move the antenna around without causing any breakup. For the first time, I could receive signals (six channels) from an antenna atop my TV, where I normally get analog channels. I now believe that any "shmo" with reception conditions similar to mine can simply take the receiver out of the box, connect a cheap loop antenna, stick it wherever it looks good, and start to receive ATSC signals from all full-power, full-pattern stations."

Conclusion

116. As consumers transition from analog television to digital television, they will need to acquire a digital television receiver. For consumers who wish to receive local TV stations over the air, a modest investment in a good quality rooftop receiving antenna (and preamplifier, in appropriate cases), just as in the analog case, is a reasonable expectation.

117. The performance of digital television receivers continues to improve with each new generation of products that are introduced into the market. The reception capabilities of DTV receivers are continually improving and the performance of early-generation receivers, as evidenced by the field test results, was sufficient to achieve a 90% System Performance Index. It is reasonable to base the service eligibility criteria on the field strength of the received DTV signal, rather than attempting to conduct subjective quality judgments at thousands of homes. We can expect that this Service Performance Index will continue to increase as new products are introduced.

118. The measurement procedures contained in Section 73.686(d) can be modified easily to reflect proper measurement methodology for DTV signals. The change in measurement instrumentation is the most significant, and there is readily available equipment in the market that is capable of measuring the DTV signal power within the integrated 6MHz channel. Also, these measurements should be performed using an antenna with some gain and directionality in

order to minimize the effects of multipath and other impairments that may lead to inaccurate power measurements.

Respectfully Submitted:

_______/s/_______________
William Meintel

_______/s/_______________
Gary Sgrignoli

_______/s/_______________
Dennis Wallace

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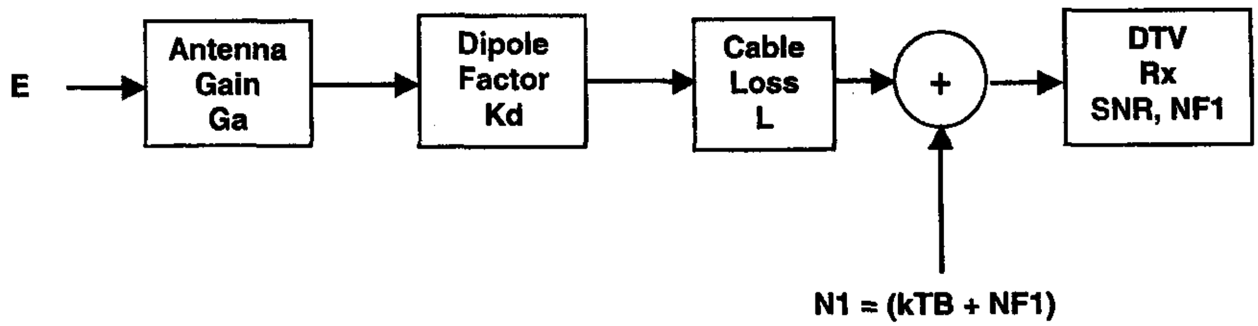
FIGURES



$$E\ (\text{dBuV/m}) = (kTB + NF1) + SNR + L + Kd - Ga$$
$$40.8\ (\text{dBuV/m}) = -106 + 7 + 15 + 4 + 130.8 - 10$$

Figure 1 **Block diagram of typical FCC receive site**

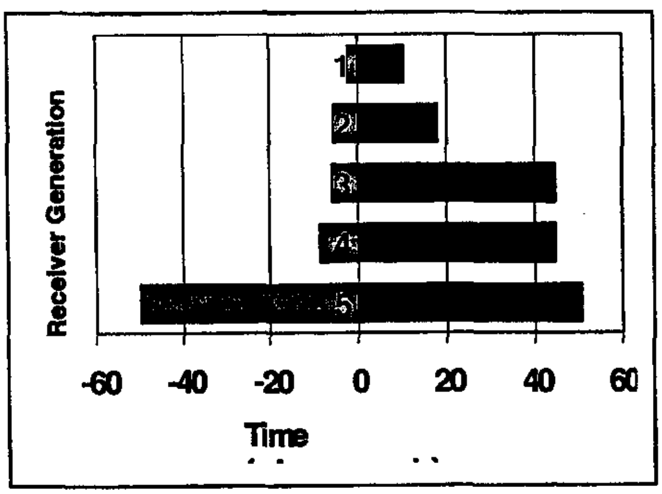


Figure 2a Equalizer delay improvement with generations

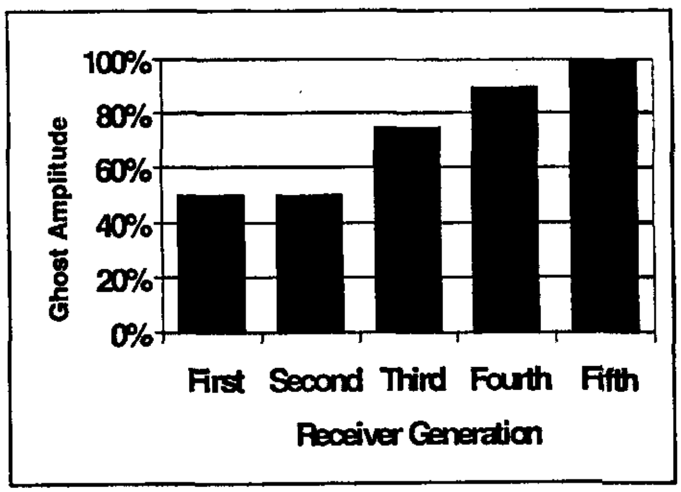
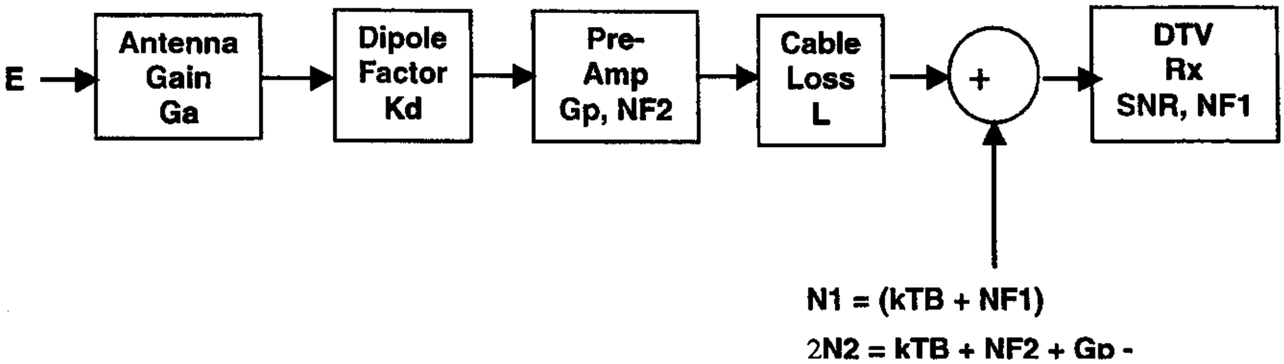


Figure 2b Equalizer amplitude improvement with generations



$$E(dBuV/m) = 10*Log\left[10^{0.1*(kTB+NF1)} + 10^{0.1*(kTB + NF2+Gp-L)}\right] + SNR + L - Gp + Kd - Ga$$

Figure 3 Block diagram of typical FCC receive site with added preamplifier

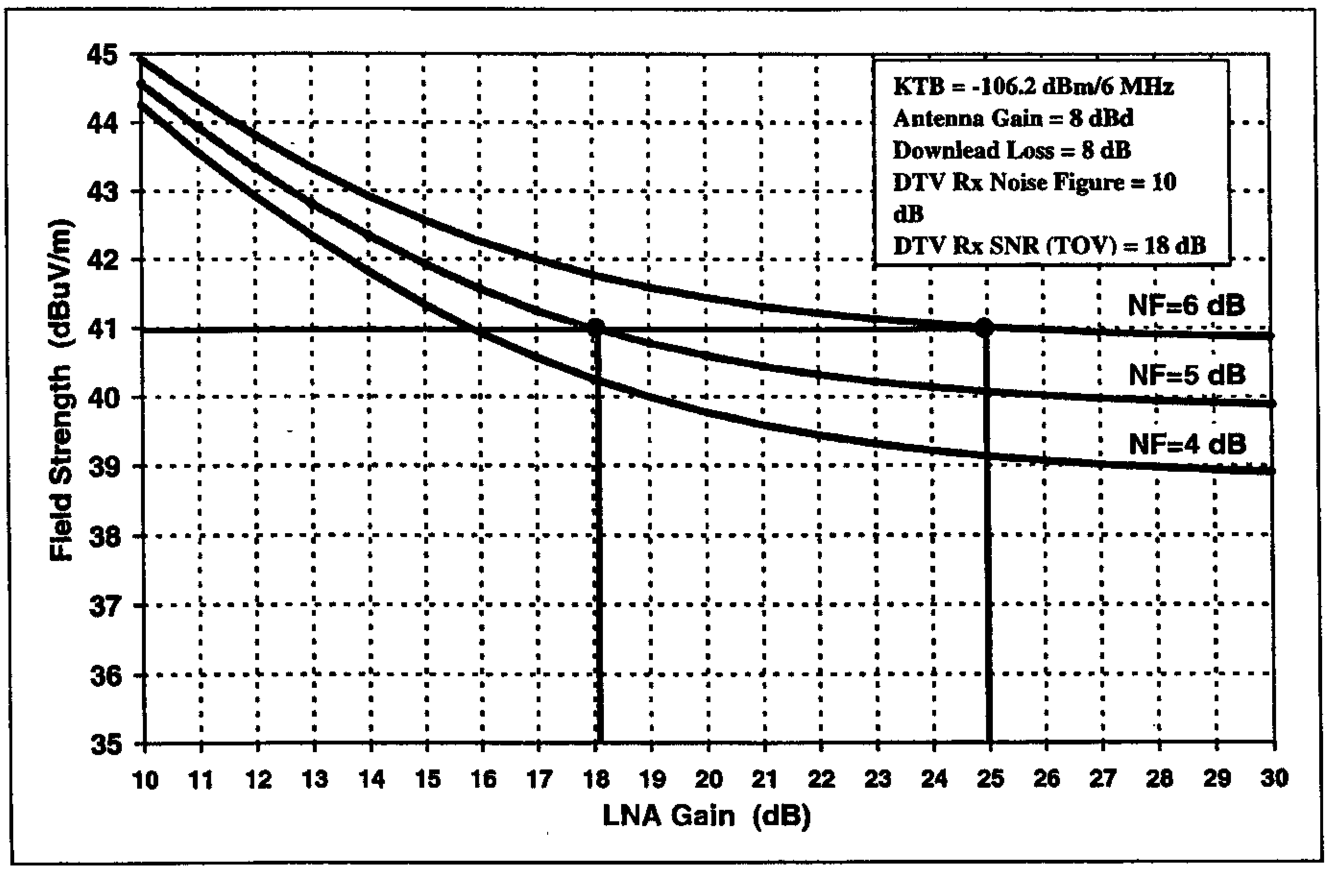


Figure 4 Field strength curves versus LNA gain for various noise figures

Exhibit A

Qualifications of the Firm
Meintel, Sgrignoli, & Wallace

William Meintel

Mr. Meintel holds a degree in Electrical Engineering and has 36 years experience in the communications field. After graduation, he was employed by the Federal Communications Commission, first as a field engineer and then in the Mass Media Bureau's Policy and Rules Division. While in Policy and Rules, he served as the division's computer expert and directed the development of several major computer modeling projects related to spectrum utilization and planning.

He entered private practice in 1989, and has been heavily involved in technical consulting, computer modeling and spectrum planning for the broadcast industry. In April 2005, Mr. Meintel merged his consulting practice into the firm Meintel, Sgrignoli, & Wallace.

Mr. Meintel co-authored a report for the NAB on spectrum requirements for Digital Audio Broadcasting (DAB), created a plan for independent television broadcasting for Romania and has been extensively involved in spectrum planning for digital television (DTV) in both the US and internationally.

Mr. Meintel wrote the coverage and interference analysis software utilized to develop the DTV Table Of Allotments and is well versed in the application of Longley-Rice and other propagation models. Mr. Meintel also wrote the software for the FCC's processing of DTV applications utilizing OET-69. He is a member of IEEE and Tau Beta Pi.

Gary Sgrignoli:

Gary Sgrignoli is a principal engineer and founder of Meintel, Sgrignoli, & Wallace. Mr. Sgrignoli received his MSEE from the University of Illinois in 1977. He was a Principal Engineer and Consulting Engineer at Zenith Electronics Corporation from 1977 till February 2004, when he left for private practice.

Mr. Sgrignoli has worked in the research, development, and design area on television "ghost" canceling, cable TV scrambling, and cable TV two-way data systems before turning to digital television transmission systems. Since 1991, he has been extensively involved in the 8-VSB transmission system design, its prototype implementation, and lab and field tests with Zenith and the Grand Alliance.

He holds 35 U.S. patents, including some that are related to digital television transmission and the 8-VSB transmission system. Mr. Sgrignoli is a recipient of the IEEE Matti S. Suikloa award presented by the IEEE Broadcast Technology Society.

He was involved with the DTV Station Project in Washington DC, helping to develop DTV RF test plans. He has also been involved with numerous television broadcast stations around the country, training them for DTV field testing and data analysis, and participated in numerous DTV over-the-air demonstrations with the Grand Alliance and the ATSC, both in the U.S. and abroad. In addition to publishing technical papers and giving presentations at various conferences, he has given many of his VSB transmission system tutorials around the country. He is a member of IEEE.

Dennis Wallace:

Dennis Wallace has an extensive background in Digital Television Systems. Mr. Wallace managed all the Laboratory RF Testing of the Grand Alliance ATSC HDTV System, having served as the RF Systems Engineer at the Advanced Television Test Center (ATTC). He managed test plans, configurations, and operations for Grand Alliance Testing and several Datacasting Systems. Prior to joining ATTC, he held positions in Field Operations Engineering, Applications Engineering, and was Product Manager for two Television transmitter manufacturers.

In July 1997, Dennis founded Wallace & Associates a broadcast engineering and consulting firm specializing in Digital Television, RF Propagation Measurements, Spectrum Policy issues, and Technical Consulting. His clients include major broadcast groups, The DTV Station Project, ATTC, Trade Associations, and both Professional and Consumer Electronics Manufacturers. In April of 2005 Wallace & Associates was merged into the firm of Meintel, Sgrignoli, & Wallace.

He has worked on the Broadcast side of the fence, as well, holding Chief Engineer and Operations Manager, positions with both Radio and Television Stations.

In 1999, Mr. Wallace was awarded the prestigious Matti S. Suikola award by the IEEE Broadcast Technology Society.

Mr. Wallace is a Certified Broadcast Television Engineer by the Society of Broadcast Engineers. He is also a member of the IEEE Broadcast Technology Society, SMPTE, an Associate member of the Federal Communications Bar Association, and is active on several industry standards committees and the ATSC.

ATTACHMENT 2

Measured Performance Parameters for Receive Antennas used in DTV Reception

Kerry W. Cozad
Dielectric Communications
Raymond, Maine

ABSTRACT

As more terrestrial-based off-air DTV programming becomes available, broadcast engineers are being asked to assist viewers in optimizing their receiving system. A typical receiving system would include a DTV receiver and display, downlead transmission line and a receiving antenna. The component with the most variability will be the receive antenna (type, orientation, mounting configuration, etc.). Utilizing input from broadcast engineers, this paper presents results from a study of typical receive antennas available to consumers. Performance parameters such as radiation patterns, polarization response and VSWR will be investigated. The objective of the investigation is to provide engineers with more detailed information regarding the in-home conditions viewers may be facing when trying to optimize off-air DTV reception.

BACKGROUND

Over-the-air TV reception concerns are as old as TV transmissions. Rabbit ears, bow-ties, loops, log periodics, etc. are familiar phrases for antenna types used for receiving TV signals at the homes of viewers. Because of the "graceful" degradation in the quality of received NTSC signals, coat hangers, aluminum foil and standing on one foot in a corner of the room have also been techniques for improving the quality of signal reception. With the introduction of cable TV and remote controls for the primary TV sets in a household, the latter techniques are typically unacceptable to the viewer as they require multiple attempts at adjustments for best picture and then when you change the channel, the process must be repeated. "Couchpotato-itis" has had a significant impact on the viewing habits of American consumers.

Since the first DTV receiving sets purchased for home use will most likely be replacements for the primary TV set now hooked up to cable through which there is presently limited access to retransmission of over-the-air digital programming, receive antenna usage is expected to increase.

Combining the consumer desire for simplicity in viewing (couchpotato-itis) and the rapid deterioration of DTV signal quality when signal margins are low, the reliability of reception when using an antenna system must be as high as possible.

PLANNING FACTORS

One method of attempting to assist in the design of reliable receiving systems is to provide accurate information that can be used by engineers to design these systems.

Receiver Planning Factors Used by PS/WP3

Planning Factors	Low VHF	High VHF	UHF
Antenna Impedance (ohms)	75	75	75
Bandwidth (MHz)	6	6	6
Thermal noise (dBm)	-106.2	-106.2	-106.2
Noise Figure (dB)	10	10	10
Frequency (MHz)	69	194	615
Antenna Factor (dBm/dBμ)	-111.7	-120.7	-130.7
Line loss (dB)	1	2	4
Antenna Gain (dB)	4	6	10
Antenna F/B ratio (dB)	10	12	14

Table 1

Table 1 is from the ACATS PS/WP3 Document 296 and is an example of the types of information needed to evaluate and design transmission/reception systems. Since the initial publishing of this table, several concerns have arisen regarding how "typical" some of these values are in commercially available products. Specifically, the receiver noise figure and antenna gain under real life conditions. We also know that multipath will impact the signal-to-noise (SNR) level at the receiver and the antenna F/B ratio may improve the rejection of multipath signals that arrive at the antenna from directions other than the primary transmitter site. One purpose for this investigation is to identify these key planning factors dependent on the receiving antenna and document measured performance of several "typical" antenna types for comparison to the performance "standards" presently being used. For real life situations, the ideal or best case conditions are not typical. The same can be said for worst case conditions. Therefore, to be able to respond to viewer concerns regarding reception issues, it is necessary for the broadcast engineer to be aware of the range of performance possible for various conditions.

GOALS

A primary goal for this investigation was to document the actual performance of typical consumer available receive antenna products for comparison to the planning factors now being used. Also, based on that comparison and any additional information that may be acquired during the testing, identify possible areas of improvement in the design or in home set up of these antennas.

DESCRIPTION OF TESTING PROTOCOL

Two methods of testing and evaluation were determined to be useful in the documentation phase: full scale range measurements and computer modeling.

For the range tests, it was desirable to use standard procedures that would maintain consistency between the measurements and data/specification sheets supplied with the sample antennas by the manufacturer. The Consumer Electronics Association Standard CEA-774-A was used for identifying the performance parameters and the IEEE Standard Test Procedures for Antennas 149-1979 was used for setting up the measurement range facility. A photo of the range layout is shown in Figure 1.

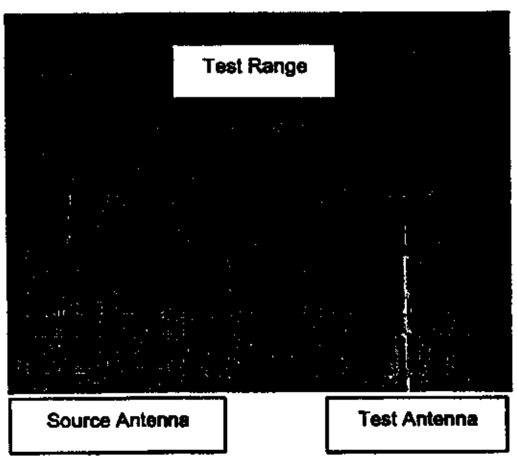


Figure 1

The outdoor far field range consisted of elevated platforms to support the source antenna and the antenna under test. The platforms were approximately 20 feet above ground level and located to minimize the effects of other objects near the range. The source antenna was a corner reflector with a dipole feed. A network analyzer was used as a signal source and receiver. A standard dipole was used to calibrate the range and then a calibrated half-wave dipole for each channel was used to measure the antenna gains by comparison. The network analyzer was also used to measure the input impedance of the antenna including any jumper cable that came with the antenna as a standard component.

Additionally, computer modeling was performed to compare results and determine the feasibility of using software analysis to simulate changes and determine improvements in the antenna designs. SuperNEC 2.7 was used for the computer modeling. SuperNEC 2.7 is a hybrid Method of Moment /Unified Theory of Diffraction antenna analysis program provided by Poynting Software (Pty) Ltd It is based on the Numerical Electromagnetics Code programs (NEC2) developed by Lawrence Livermore Labs in 1982. The program allows for inputting 2-D and 3-D models for simulation of electromagnetic characteristics such as radiation patterns, current flow, voltage levels and gain calculations.

The primary performance parameters to be tested were:

Antenna Principal Plane Patterns
- Azimuth Pattern
- Elevation Pattern

Polarization Response
- Horizontal
- Vertical

Frequency Response
- Variations within design band
- Response out of design band

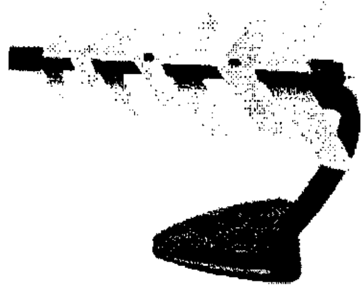
Directivity

Gain

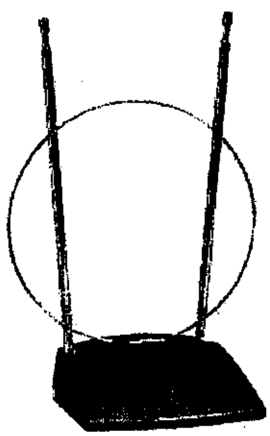
PRODUCTS TESTED

The receive antenna types to be tested were chosen based on availability to the consumer, specific design for the band of interest and to provide comparisons between typical types from different manufacturers. They were divided into two types based on whether they would be mounted inside or outside the home.

"Set Top" (indoor)



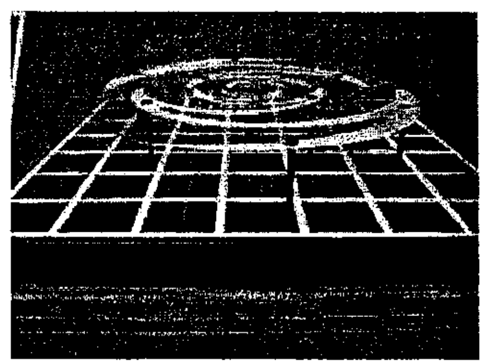
Zenith Silver Sensor



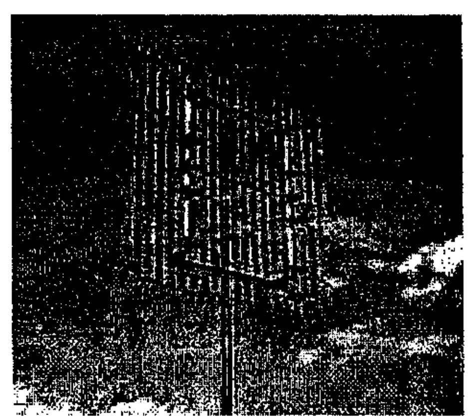
Radio Shack 15-1864 Loop

Terk Antenna Pro

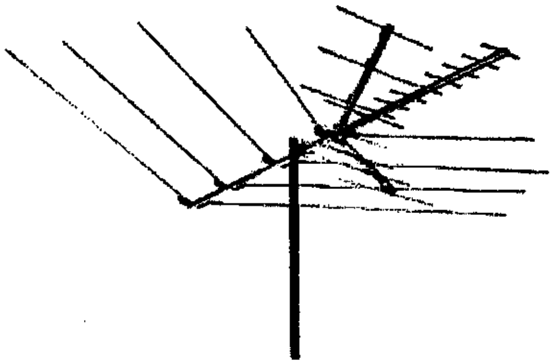
Attic or Outdoor



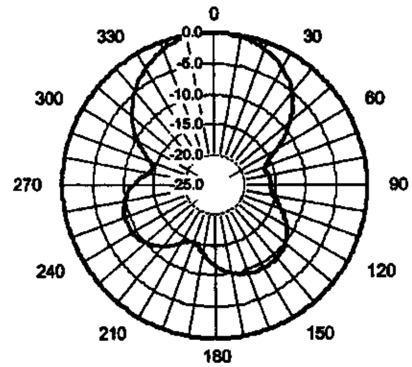
Winegard SS-1000



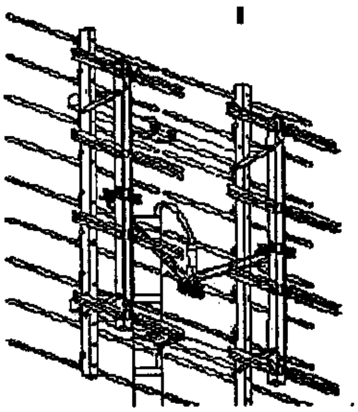
Channel Master 4228



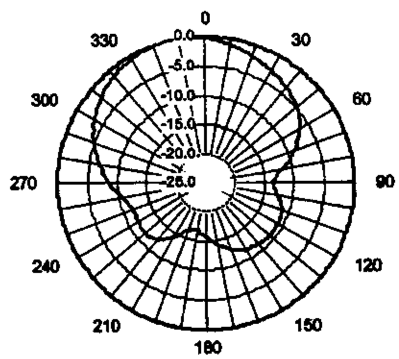
RCA ANT3020



Silver Sensor: Azimuth



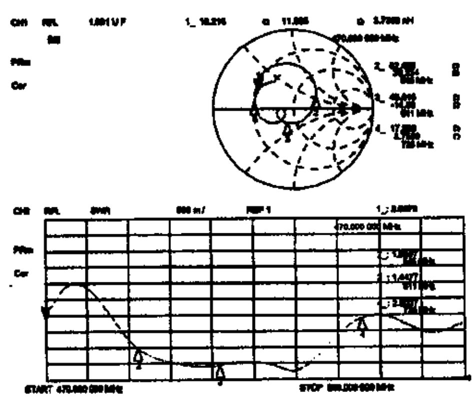
Winegard PR-8800



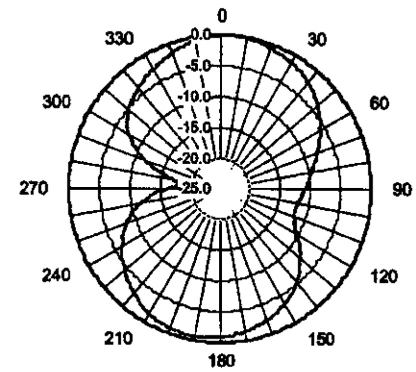
Silver Sensor: Elevation

MEASURED RESULTS

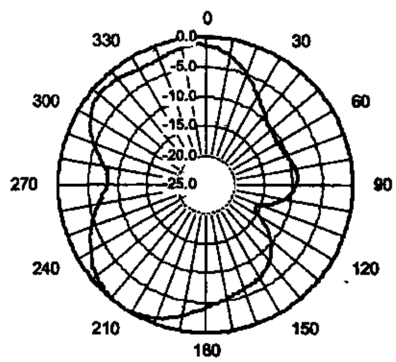
The amount of measurement data acquired during the testing of these antennas prohibits presentation of all the data in this paper. If the reader is interested in the specific data, please contact the author at the address included at the end of the paper. Below are samples of the data measured on two of the typical indoor antenna types. A summary of parameters for more samples of the antennas is included in a later section of this paper.



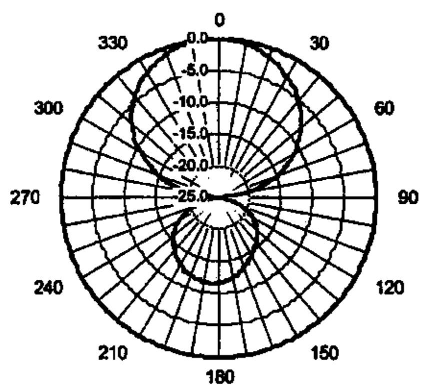
Silver Sensor VSWR



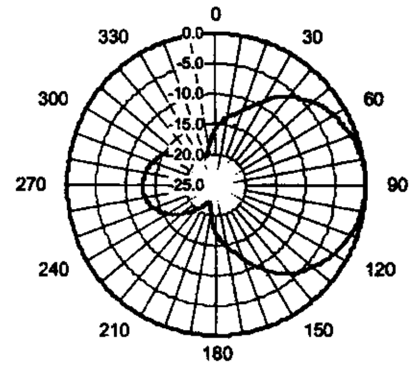
Radio Shack 1864: Azimuth



Radio Shack 1864: Elevation



Winegard SquareShooter: Azimuth



Winegard SquareShooter: Elevation

The previous measurements were all taken in the horizontal polarization mode. Data was also taken in the vertical polarization and the gains were compared to determine the effectiveness of the standard antenna to receive cross-polarized signals. This information can be used to study the use of transmitting cross-polarized signals to minimize interference or the reception of multipath echoes. A sample comparison is shown in Table 2.

Average V-Pol/H-Pol Ratios

Zenith	-20 dB
Channel Master	-19 dB
Radio Shack 1864	-5 dB

Table 2

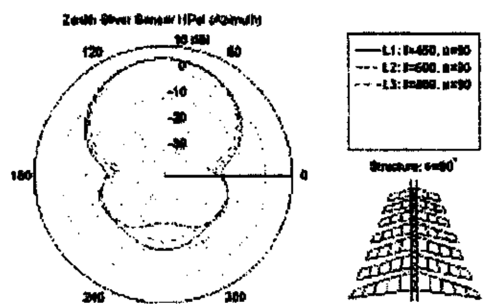
OBSERVATIONS FROM MEASURED DATA

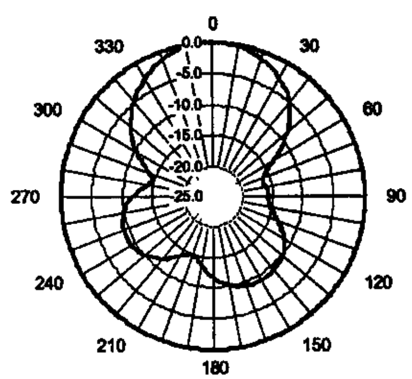
There were two basic antenna designs tested: the loop indoor antenna and a linear array of elements. The loop antenna was the less directional design and therefore exhibited lower gains. It also showed the greater sensitivity to receiving polarizations other than horizontal which could be a benefit for broadcasters that choose to transmit a vertically polarized signal along with the horizontally polarized signal to improve close in coverage and penetration through buildings but would not be a benefit in minimizing the reception of multipath. The higher gain receive antennas that would typically be used for locations at some distance from the transmitter have more defined pattern shapes with a specific directionality in the direction of the array. This provides for the ability to "aim" the antenna for maximum signal and minimize reception of multipath reflections for other directions. Any benefit that might be provided by transmitting a vertically polarized signal was not apparent.

The one exception to the general antenna types described above was the Winegard SquareShooter. Its design is shown in the photo earlier and is a log periodic style design for broadband performance. It was thought that the vertically polarized signal response would be different for this design relative to the linear array antennas. It was more sensitive to vertical polarization but the levels were still more than –10dB those for horizontal polarization.

COMPUTER MODELS

Several of the antennas were also modeled using SuperNec 2.7. The primary purpose of this exercise was to compare calculated to measured data so that any investigations into improved designs for the antennas could be accomplished quickly in the lab versus having to build a physical prototype of each antenna for testing on the model range. Examples of this data are presented below.





Zenith Silver Sensor
Measured H-Pol Azimuth Pattern

GAIN COMPARISONS

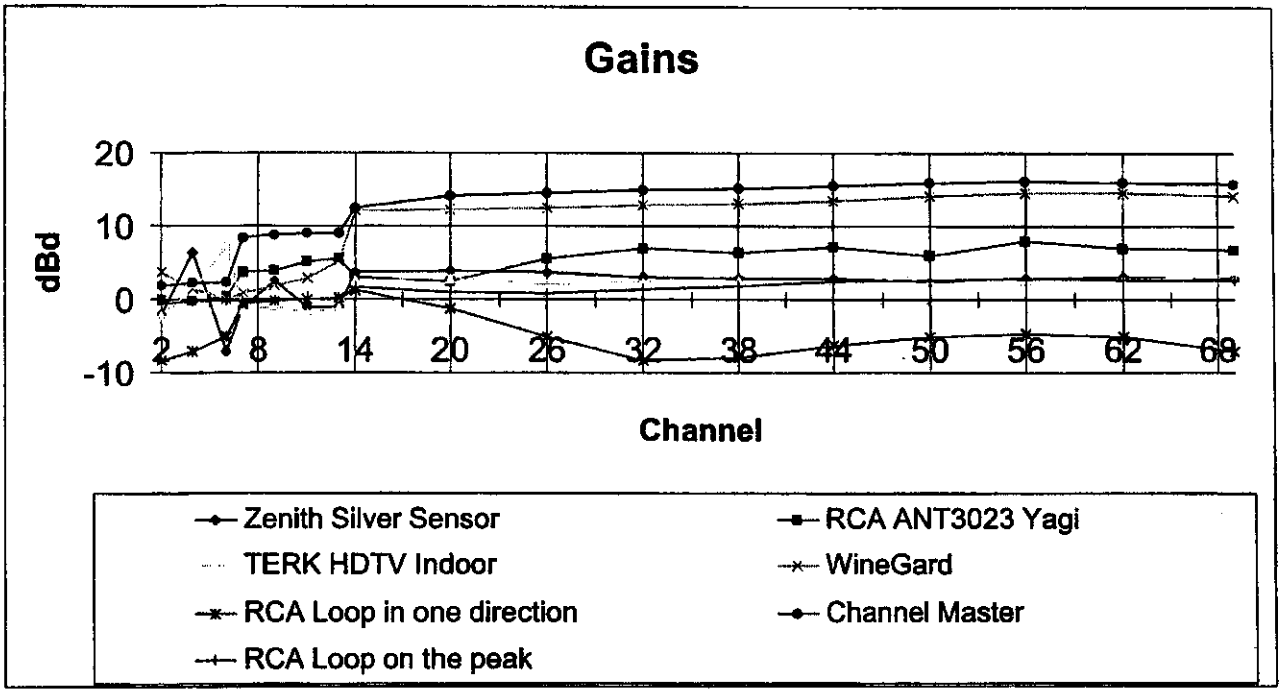
A graph showing a comparison of calculated gain performance for the antennas relative to channel is included on the next page. One of the more interesting questions that arose during this investigation was the performance of UHF specific antennas at VHF channels 7-13. Since most DTV channels presently in operation are UHF, concerns about moving back to the present High Band VHF NTSC channel later for DTV transmission and the impact on over-the-air viewers that were using UHF only receive antennas could be a critical decision point. Based on this data, small, compact designs that would be used indoors did not perform as well as the outdoor designs that used two-dimensional arrays of dipole elements. It is believed that the feed systems for these larger arrays provided additional area for current flow at the lower frequencies and therefore improved the received signal levels for channels 7-13.

Also noted is that only the larger, outdoor antenna designs will meet the 10 dB gain parameter for UHF unless an amplifier is used with the antenna. This certainly brings at least one more factor into the equation relative to the quality of the amplifier system used. That concern was not part of this investigation.

SUMMARY

Only a small sample of the measurements made is presented in this paper. Measured gains will be presented at the NAB Engineering Conference, as they were not available at the time of writing of this paper, as well as additional pattern analysis data.

It is clear that accurate measured data can provide significant insights for the broadcast engineer when responding to reception concerns by viewers. Knowledge of the effectiveness of antenna types relative to distance from the transmitting site (gain and directional characteristics), multipath rejection, and performance over multiple channel bands can be areas that will assist broadcast engineers in working with viewers to optimize reception. It is the hope of the author that the information previously presented at the 2004 IEEE Broadcast Symposium, and the information provided in this paper and at the 2005 NAB Engineering Conference will be helpful to broadcast engineers during the ongoing transition to digital television around the world.



ACKNOWLEDGEMENTS

The author would like to thank Mr. Andy Bater of Tribune Broadcasting for his support of this work and providing most of the antennas used in the testing. Also, many thanks to the Broadcast engineering staff at Dielectric Communications for their assistance in developing the test range, performing the measurements and analysis of the data.

FOR ADDITIONAL INFORMATION

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ATTACHMENT 3

Performance of 5th Generation 8-VSB Receivers

Tim Laud, Mark Aitken, Wayne Bretl, K. Y. Kwak

Abstract — *There has been a focused effort within the television broadcast industry to move DTV receiver technology "state-of-the-art" forward to better deal with the more difficult and complex receiving environments faced within the TV viewing environment. In this paper, we detail the approach taken which today provides the broadcast industry with a "breakthrough" 8-VSB receiver product that has "cleared the bar" of expected performance for the simple consumer-friendly reception of over-the-air digital television in most complex environments.*

There have been many field tests and studies performed since the adoption of the 8-VSB ATSC standard. Armed with a more complete understanding of the adverse environments where prior 8-VSB receivers fell short of providing acceptable reception, it became clear that an architecturally advanced approach was needed. Having new and advanced methods of analyzing captured RF signals, coupled with new-found capabilities of more accurately defining and applying such "real world" approximations in the realm of software simulation, led to an understanding of many modeled performance capabilities prior to hardware production. A variety of tools allowed the design team to depart from the generally accepted implementations of the past, and to deal in new ways with the infinitely complex array of variable ghost delays and amplitudes required to meet the needs of broadcasters and consumer electronics manufacturers alike. Affirming knowledge about the need to deal with known interferences, resulting from an increasingly densely packed RF broadcast television spectrum is also highlighted.

Field evaluation data is presented to confirm the conclusions. Providing correlation of results with laboratory simulations and tests with those "real world" conditions in various field trials conducted by multiple parties enables this technology to achieve quick acceptance in the marketplace.[1]

Index Terms — VSB, Digital Broadcast Television, DTV Receivers

I. Introduction

EACH generation of 8-VSB demodulator has shown a performance improvement. A new generation has appeared approximately every two years since the US adoption of a digital TV standard. This paper documents some of those improvements with emphasis on the most recent step from 4th to 5th generation. Lab results are presented along with simulated and actual field results.

II. Fifth Generation Advances

The performance improvements of the 5th generation receiver enable reception using simple antennas such as bow ties, loops and rabbit ears. Sensitivity to antenna positioning with respect to the propagated signal will now be very low. The need to adjust the antenna when changing channels will be almost non-existent, providing viewers with the main criterion for "ease of reception".

The new equalizer architecture and algorithm enhance convergence under combinations of complex ghosts, severe ghosts and noise. Also, the equalizer architecture now supports longer-delayed ghosts and has a symmetric capability for pre and post ghosts.

The ghost cancellation circuit has several features that contribute to the enhanced performance. Initialization is based on an accurate channel impulse response estimate rather than a fixed starting condition. Dynamic ghost tracking then uses an LMS algorithm to update equalizer taps. A zero-delay trellis decoder improves the accuracy of the update estimates and improves the Doppler (rate of change) performance. Techniques for reduced noise enhancement improve accuracy.

III. Equalizer Improvements of Various Generations

From the beginning of digital television development, it was recognized that multipath was an issue that would need to be addressed, especially for indoor reception. However, since automatic ghost canceling of the complexity required for digital reception had not been previously implemented in any analog product, there was little data on the severity and nature of the problem.

The very first generation of 8-VSB demodulators marketed included equalizers that assumed significant ghosts were within 10 microseconds of the main signal and their amplitude was no greater than half the main. Field measurements quickly showed this to be true for less than 70% of a typical TV coverage area.

A second generation design was introduced early on and used for the greatest number of field tests. Hence, most of the reception studies are based on this level of performance.

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Contributed Paper
Manuscript received September 15, 2004

Subsequent generations of demodulators were designed with longer equalizers. (See Fig. 1.) New iterations handled more ghost scenarios than the previous implementations. Each generation essentially doubled the post ghost capability, pre-ghost capability, or both. Analysis of signals at difficult sites has shown that the earlier assumption that the strongest signal occurs among the first arrivals is often incorrect. Therefore, the 5th generation has added the capability to handle 50 microsecond pre-ghosts or post-ghosts.

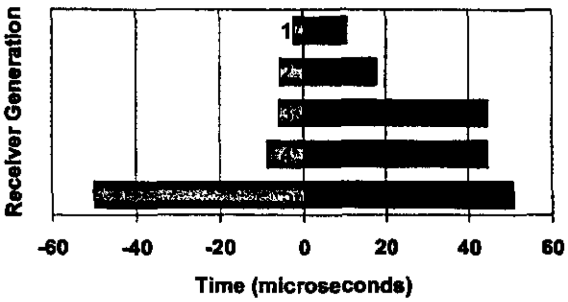

Fig. 1. Length of equalizer capability for each generation of 8-VSB receiver.

In addition to ghost delay lengths, it was recognized that improvements in ghost amplitude handling were necessary. While the original assumption that the first signal arrival from the transmitter would be the strongest seemed reasonable, it is a poor fit to the scenario of indoor and "concrete canyon" reception. In these cases, the direct path from the transmitter is frequently blocked and the initial wave may be much smaller than the reflections. To address this, each generation improved the algorithm for ghost cancellation. This allowed reception in an increasing number of locations. Whereas the early equalizers could handle only a 50% amplitude ghost, the latest implementations can handle a reasonable ensemble of 100% ghosts. (See Fig. 2.)

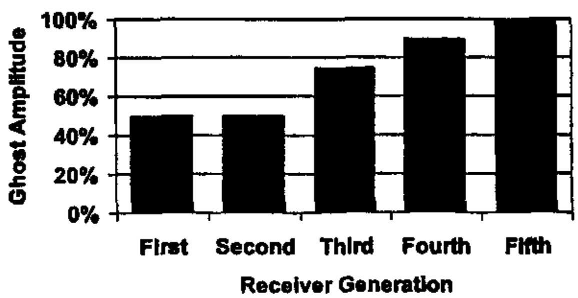

Fig. 2. Maximum ghost amplitude handling for each generation of 8-VSB receiver.

IV. Laboratory Tests

From Figs. 1 and 2, it is easy to see that the new equalizer architecture of the 5th generation is a big step forward. To characterize this improvement in performance, each generation of hardware has been tested in the laboratory against several ghost ensembles. Each ensemble typically has been composed of 6 signals (a limitation of the test apparatus) of varying amplitudes and delays. The most common ensembles used in recent tests are listed in Table 1 [1]. Ghost complexity generally increases from the top to the bottom of the table.

ATTC D was defined early in the U.S. DTV trials. The ghosts are relatively simple and low energy.

Brazil A is a minor variation on ATTC D.

Brazil B includes a few strong ghosts at moderate delays.

Brazil C and D represent indoor scenarios of very strong, close-in ghosts. Brazil D is primarily pre-ghosts.

Brazil E represents an unusual but possible extreme case in a single frequency network. Three signals of equal strengths are separated by one microsecond.

The CRC ensembles consist of a number of strong and moderate ghosts of short delay plus one of long delay.

The results of each generation's performance against these ghost scenarios are summarized in Table 1. (First generation hardware is no longer maintained or tested since its marginal performance is well documented.) The 5th generation chip exhibits a clear breakthrough in laboratory ghost performance.

	2nd	3rd	4th	5th Gen
ATTC D	Pass	Pass	Pass	Pass
Brazil A	Pass	Pass	Pass	Pass
Brazil B	Fail	Fail	Fail	Pass
Brazil C	Fail	Fail	Pass	Pass
Brazil D	Fail	Fail	Fail	Pass
Brazil E	Fail	Fail	Fail	Pass
CRC 3	Fail	Fail	Fail	Pass
CRC 4	Fail	Fail	Fail	Pass

Table 1. Ensembles used to measure equalizer performance have been collected from international test labs.

A better understanding of real world performance requires field testing. However, the variations in field conditions from time to time make it impossible to repeat a measurement, so that field test must use a large number of measurements and analyze the results statistically. A few years ago, methods of recording and playing back the RF signal found in the field were developed. This allows the repeated and comparative testing of demodulator designs. During field tests conducted by MSTV (Association for Maximum Service Television) in Washington DC and New York City, RF captures were taken at difficult locations. Fifty of these captures are called out in the ATSC (Advanced Television Systems Committee) Recommended Practice A/74: Receiver Performance Guidelines [2].

The 4th and 5th generation receivers were tested against these RF captures. Note that the captures may have multiple impairments, e.g., noise and/or interference, in addition to ghosting. The results are shown in Fig. 3. The number of failures was cut by a factor of 5. Keeping in mind the known extreme difficult nature of these captures, with this degree of improvement, field performance enhancement should be quite dramatic. While these RF captures can provide an understanding of performance within the specific channel bandwidth captured, interference and noise within the adjacent spectrum, must be factored in to adequately understand other "real world" performance parameters.

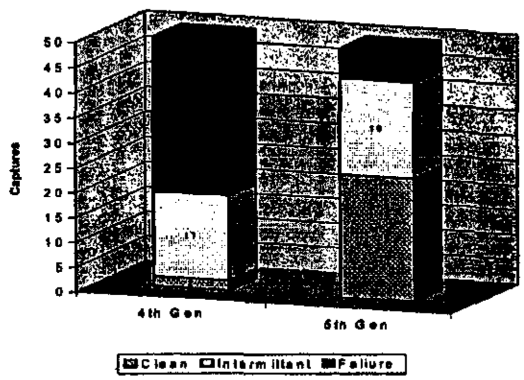

Fig. 3. Performance of 4th and 5th generation receivers against RF captures.

V. Field Tests

At some point in the reiterative design/review/improvement process, it is necessary to assess "real world" performance. It is not possible to assign totally objective criteria to define the many variables associated with field test sites. However, statistical analysis of reception success and the analysis of captured spectrum data do allow an understanding of varying degrees of difficulty. Well-documented sites and areas that have historically been "difficult" provide a good place to assess relative performance of generations of receiver technologies.

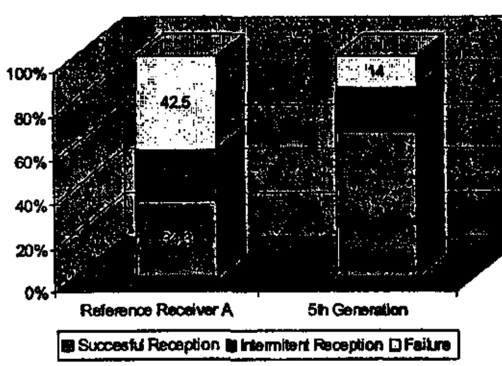

Fig. 4. Field Reception Results in Washington DC.

The 5th generation receiver was tested in Washington DC during the summer of 2003 by MSTV at numerous known difficult locations. Many of these locations have been identified since the second generation receivers were field tested. A reference receiver of understood and documented performance was tested simultaneously to provide a ready "benchmark". This provides a good measure against the recent state of the art. In Fig. 4, it can be seen that the number of reception failures was reduced by a factor of 3.

Similarly, independent tests were performed by the Communications Research Center in Canada during 2004. The results were presented at the SET conference in Brazil of August 2004 [3]. The improvement in reception vs. a reference receiver is shown in Fig. 5. Data shown here is for a single transmitter and a directional receiving antenna.

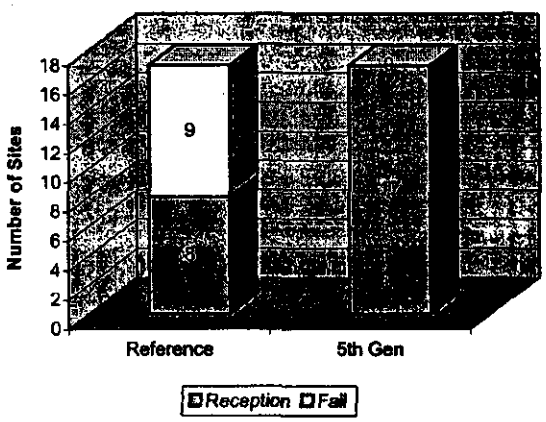

Fig. 5. Field Reception Results in Ottawa, Canada.

A structured series of tests in well-documented difficult environs in and around Baltimore was conducted in the Spring of 2004[2]. Based on the performance of earlier generations of products, many of these documented sites are challenging to earlier generations of receivers, and present an opportunity for side-by-side "real world" testing. All of the sites chosen had signal strength well above the minimum required by the receivers under test, so that the effects of ghosting and interference were dominant.

Earlier evaluation had also made note of some performance issues associated with adjacent channel interference, both first and second. (Channel 46DT is adjacent to Channel 45 NTSC and Channel 52DT is close to Channel 54 NTSC as shown in Fig. 6).

The test setup included a tunable band-pass-filter with moderate rejection characteristics (~35MHz bandwidth) that could be adjusted to identify possible effects of these adjacent (and other) sources of interference. While both 2nd and 4th generation receivers were positively influenced by use of the bandpass in a small number of locations, it was difficult to

[2] Tests were conducted by engineers from Sinclair Broadcast Group and *Zenith Electronics Corp.*

determine any significant impact on the performance of the 5th generation product. This improvement may be attributable to differences in RF tuner performance in addition to characteristics of the demodulator integrated circuits.

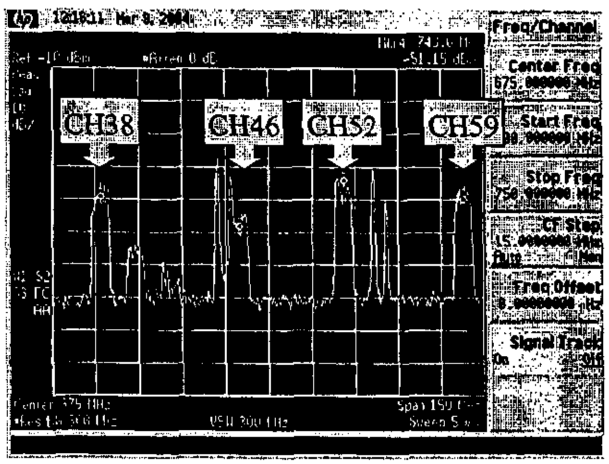

Fig. 6. Baltimore Spectrum

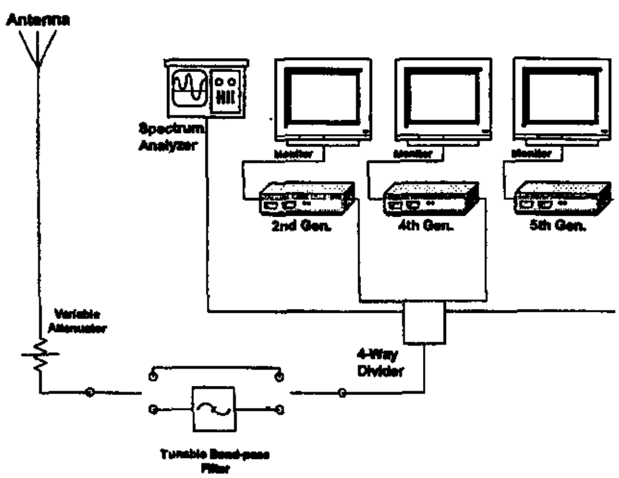

Fig. 7. Simplified Test System Diagram

Multiple sites were chosen, and a comparative test was conducted noting the received/displayed video performance as primary indicator. The system illustrated in Fig. 7 was used to provide simultaneous display of the receiving characteristics of three generations of receivers. Calibrated spectrum power and shape were recorded, showing amplitude/frequency variations. This setup allows study of the effects of various site-specific variables (such as antenna orientation/placement, traffic and path attenuation.) and resulting impact on reception. The following is a simplified version of the test procedure:

1. Arrive at selected location and set the receiving antenna/tripod at a fixed test position. (The location of the tripod was random to the extent that the vehicle could be parked legally and safely).
2. Connect the selected TV antenna (simple bowtie at 2m height) to the system as indicated in Fig. 7.
3. Orient the antenna for maximum integrated power on an available DTV broadcast. (In this case channel 38 with a center frequency of 617 MHz was used)
4. Record the reference values, and note presence (or lack) of video output from DTV receivers. Note site-specific variables and note impact on reception

Several antenna types were used at various locations, but a simple "bowtie" antenna was used for all of the comparative tests of "ease of receivability." This simple antenna provides a broad incidence of reception (mostly non-directional) at UHF frequencies, providing a means to assess the ability to receive multiple channels without a need to adjust receiving antenna pointing. This is important in the simple home receiving environment.

There was good correlation with results obtained in prior tests at the same locations with both the 2nd and 4th generation receiver products. This provided a way to gauge the real performance differences with the 5th generation product. The results in Fig. 8 indicate performance enhancements in the 5th generation product that closely match the expectations as a result of the previous promising laboratory and simulated environment tests.

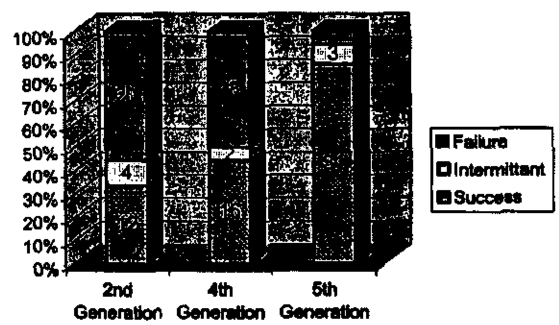

Fig. 8. Baltimore "Ease of Reception" Test Results

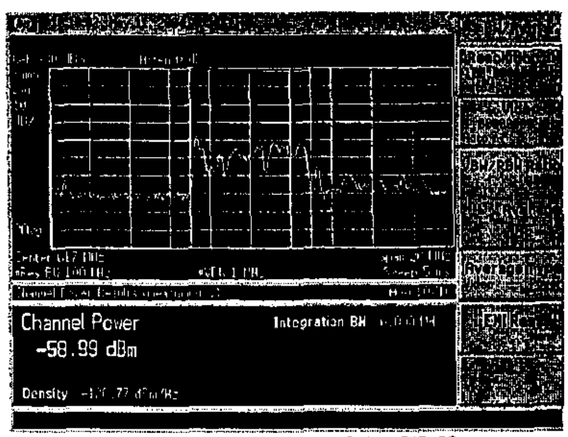

Fig. 9. Example Spectrum, DTV CH. 38

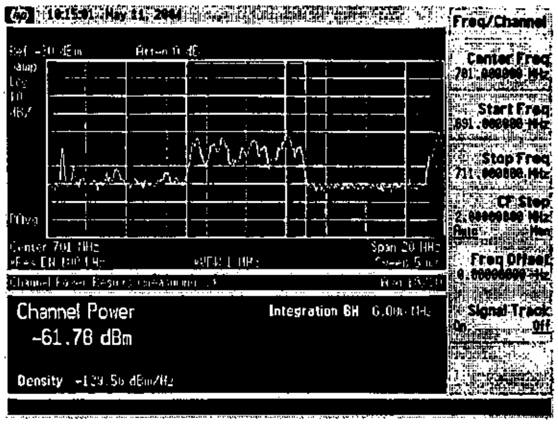

Fig. 10. Example Spectrum, DTV CH. 52

Even in some of the most difficult sites, with multipath very evident in the spectrum (Fig. 9 and Fig. 10), reception was possible with the 5th generation receiver.

VI. Future Enhancements

Improvements in receiver performance beyond fifth generation are still possible. Improvements are planned for equalizer convergence speed, particularly to address the portable environment. Adjacent channel interference can be addressed in two ways. Changes in tuner AGC methodology can address overload conditions experienced with the more densely packed broadcast spectrum. The effects on reception of digital stations can be reduced by operating them at full licensed power, especially when they are in a spectrum with powerful adjacent or nearly adjacent analog stations.

VII. Conclusion

Because of the need to free up spectrum for a variety of interests and uses, an increasing burden has been placed on all involved in the FCC mandated DTV transition. Because of the "all or nothing" nature of digital reception, digital TV must provide excellent reception even where analog reception is poor, in order to facilitate the transition for the large number of receivers that use over-the air reception. This is beyond the requirements originally proposed at the inception of digital television, but it is being met by 5th generation designs.

Development of the successive generations of demodulators has depended on a cooperative effort of broadcasters and receiver designers to better understand expectations, identify the real world problems associated with digital terrestrial transmission/reception and define test protocols that more fully represent that real world (for example the ATSC recommended practice A/74).

Proper matching of the application design efforts to the discovered realities of digital terrestrial reception has resulted in 5th generation hardware that clearly supports identified needs of the digital transition.

References

[1] Communications Research Centre Canada, "Results of the Laboratory Evaluation of Zenith 5th generation VSB Television Receiver for Terrestrial Broadcasting," http://www.crc.ca/en/html/crc/home/research/broadcast/rtnt , Appendix A, September 2003.

[2] Advanced Television Systems Committee, "ATSC Recommended Practice: Receiver Performance Guidelines," http://www.atsc.org/standards/practices.html, Annex A, June 2004.

[3] Communications Research Centre Canada, "Results of the Laboratory Evaluation of Zenith 5th generation VSB Television Receiver for Terrestrial Broadcasting," http://www.crc.ca/en/html/crc/home/research/broadcast/rtnt, September 2003.

Biographies

Timothy Laud (M'74) is a Senior Member of the Technical Staff for Zenith Electronics Corporation. Tim attended Purdue University where he received his BSEE in 1975 and MSEE in 1976. After a brief period at Motorola, Tim joined the Zenith R&D team in 1980. He has been involved in the development of VSB and E-VSB since their inceptions.

Mark A. Aitken is Dir. of Advanced Technology, Sinclair Broadcast Group. Educated at Springfield Technical Community College with continuing education in Eng. Mgmt. at Rensselaer Polytechnic Institute, he represents SBG within many industry related organizations including ATSC. Mr. Aitken is a member of AFCCE and IEEE, involved with advanced digital television systems design and implementation.

Wayne Bretl is a Principal Engineer in the R&D Department at Zenith Electronics. He received the BSEE from Illinois Institute of Technology in 1966, and joined Zenith in 1975. He holds over 15 patents in television technology and related areas. He is a member of IEEE, SMPTE, AES, and SID, and represents Zenith in ATSC and a number of professional and industry associations.

Kook Yeon Kwak has been developing technology and ASICs for VSB, QAM and COFDM as a research fellow in the DTV laboratory of LG Electronics since 1999. He joined LG Electronics in Korea in 1979. He received the B.S. degree in electronic engineering at National Seoul University in Korea in 1979, the M.S. degree in electrical engineering from KAIST in Korea in 1984, and the Ph.D. degree in electrical engineering from Polytechnic University in NY in 1995.

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"Communicate, don't ex-communicate"

From the Desk of:

Paul Robinson

"Above all else... We shall go on..."
"...And continue!"

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Transmittal Letter

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To the Secretary, Federal Communications Commission:

Enclosed are 5 copies of my reply to the Commission's inquiry in docket 05-182, "Technical Standards for Determining Eligibility For Satellite-Delivered Network Signals Pursuant To the Satellite Home Viewer Extension and Reauthorization Act."

Sincerely Yours,

Paul Robinson

Paul Robinson
"A computer programmer and
Notary Public in and for the
Commonwealth of Virginia, at large"
General Manager
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